Recommendations for Assuring the Quality

of the Geonor Precipitation Data

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Prepared for the U.S. Climate Reference Network Management Office

January 2003

Executive Summary

This report outlines strategies for assuring the quality of the Geonor precipitation gauge data. The quality assurance recommendations presented in this document were derived from analysis of 20 months of data collected by six gauges at the National Center for Atmospheric Research (NCAR) Marshall Test Facility near Boulder, Colorado. The site is located just east of the foothills of Colorado's Front Range and typically experiences less 16 inches of precipitation per year.

The Geonor gauges will be operated at each Climate Reference Network (CRN) site to obtain estimates of precipitation and are generally considered to exhibit consistent, stable behavior over time. The CRN's long-term monitoring objectives require any problems that do occur to be adequately addressed to insure data quality.

The Geonor gauge operated at each CRN site uses a three-wire modification of the traditional system of one wire and two chains. This three-wire modification allows the accumulation bucket to be supported by three wires rather than one, decreasing the measurements' sensitivity to the leveling of the instrument. The three-wire system provides some redundancy, in case the ability of one of the three sensors to communicate valid information should fail. The information provided by the other two wires can be used to both diagnose and correct these problems. If a wire itself should break or become inoperable, however, the data recorded by the other two wires will not be valid. The manufacturer reports that the wires tend to have very long operating lives, with failures occurring only rarely.

The mechanics of the Geonor instrument suggest at least six possible problems that could affect the precipitation record. First, a wire could break, causing the other two wires give useless information. A problem of this type should be easy to detect, and would need to be fixed as soon as possible. Second, the "plucking" / "hearing" system within a sensor could go bad. This problem would be unlikely to affect measurements from the other two sensors. Third, the calibration of a wire could change. The wires generally show strong stability and the two other wires would likely provide good information if such a problem occurred, but the wire would need to be recalibrated or replaced during the next site visit. Fourth, the bucket could overfill, either with precipitation or debris. The data can provide an indication of when a bucket needs to be emptied, but debris in buckets will likely only be diagnosed from a site visit. Fifth, the bucket could shift out of alignment. The three-wire system allows for small misalignments, but beyond a certain threshold, a misalignment may be large enough to influence the quality of the data. Alignment changes can be easily monitored with the three-wire configuration and should be able to diagnosed within one day. Sixth, the data acquisition system could fail. These problems could involve numerous signals, but should be able to be quickly diagnosed.

Some occurrences of the six problems outlined above are likely to be detected through appropriate quality assurance tests. These tests are outlined in Section Four and in Appendix 1 of the report and involve a multi-pass system to evaluate the overall quality of the data.

The first tier of quality assurance (first pass processing) should be completed daily and will verify that a daily download file exists and that the file is of appropriate size. It will also verify that the file contains only readable, numeric ascii characters and that the header data (including site location, calibration numbers, and date) are appropriate. Failure of any of these tests will require a check to evaluate what type of problem has occurred.

The second tier of quality assurance (second pass processing) will be done daily to test the one-minute values to make sure there have been no sudden problems or shifts with the measurements. The second pass processing includes seven tests, checking 1) the magnitudes of the frequencies and gauge readings, 2) the wire-to-wire variations, 3) the overall range (max minus min) of the frequencies and gauge readings, 4) the magnitude of upward jumps, 5) the magnitude of downward jumps, 6) agreement among the sensors, and 7) agreement in derived precipitation from each sensor.

Each of these seven tests will be evaluated at four threshold levels, with the levels to be derived from the known operating procedures of the instrument and from known, expected climatology at each of the sites. Preliminary data collected at each location will also help in developing specific thresholds for that site. The data will be tested against the following four levels of thresholds: a suspicious value for the site, an alarm value for the site, a suspicious value for the network as a whole, and an alarm value for the network as a whole. The suspicious values may be able to be verified or corrected for eventual use in analysis. Alarm values would be considered bad data and eliminated from any long-term climate analysis.

On a weekly or monthly basis, a third tier of quality assurance (third pass processing) will proceed. This third pass processing will evaluate running averages of daily precipitation over one-week, three-month, and one-year time periods. Each of these time periods will be evaluated at four levels, specifying thresholds for suspicious and alarm data, for the network and for the individual site as described above.

The fourth tier of quality assurance (fourth pass processing) will involve examining the site visit reports. These site visits are required for the data to receive full quality assurance, and should provide information on the contents of the bucket and its alignment. This information will be used to determine whether adjustments to the data are required. Records of the times the bucket was emptied and restocked will be necessary for resetting the data management files.

Developing an automated quality assurance algorithm for the Geonor data will be an iterative process requiring some time of field operation to determine normal and anomalous behavior of the instruments. Many of the criteria for normal and suspicious behavior will be site dependent and will likely be determined during the first year of operation at a particular location.

Report

This report outlines recommendations for assuring the quality of the Climate Reference Network (CRN) and is based on analysis of the National Center for Atmospheric Research (NCAR) Geonor precipitation measurements. These recommendations are preliminary and developing algorithms to assure the multi-site data is likely to be an iterative process. The report contains multiple sections and appendices. Section One offers an overview of the Geonor instrument. Section Two describes possible problems with the measurements. Section Three describes the evaluation and analysis of data collected by six Geonor precipitation gauges near Boulder, Colorado. Section Four presents specific recommendations for assuring the quality of the data, and suggests an outline for a multi-pass quality assurance routine. Section Five describes the two types of quality assurance flags that will need to be developed, and Section Six offers some conclusions concerning adequate quality assurance of the data. Flowcharts for each series of testing recommended to assure to quality of the data are included in Appendix 1. Appendix 2 lists the recommended test parameters for the Geonor gauges in Boulder, Colorado. Appendix 3 includes supplementary information on weather conditions during the operating time of the NCAR gauges.

The quality assurance recommendations presented in this document were derived from analysis of 20 months of data collected from six Geonor gauges. There are a number of differences between the NCAR data sampling and the CRN sampling. The NCAR data were analyzed as one-minute values, which differ from the CRN's expected reporting period of 15-minute averages. Furthermore, all six gauges were operated at the NCAR Marshall Test Facility near Boulder, Colorado, an area that typically receives less than 16 inches of precipitation each year. Data from a single location may not be representative of gauge behavior for the entire network, and developing quality assurance parameters is therefore likely to require an iterative process.

I. The Geonor precipitation gauge.

The Geonor gauges collect precipitation using a bucket system (Figure 1) suspended by three wires. Accumulated precipitation corresponds to changes in the tension on the wires, which measured by magnetically "plucking" the wire and recording the peak frequency. In the normal collection mode, the bucket (Figure 2) contains both antifreeze and oil to minimize any freezing or evaporation of the collected precipitation. The values reported are therefore a continual accumulation, and the bucket's 600-mm capacity (Geonor T200-B Users Manual) allows continuous, unassisted operation for long time periods. In its user specifications, Geonor recommends emptying/replenishing the bucket every six months.

The Geonor gauges used by CRN employ a three-wire system to support the bucket and report accumulated precipitation. This three-wire system is used only by CRN and allows the weight of the bucket to be supported equally by the three wires. In the traditional operating mode, two stationary struts and one wire support the bucket, making the measurements extremely sensitive to the leveling of the instrument. The three-wire mode helps alleviate this sensitivity and provides some redundancy in terms of data reporting.

Precipitation estimates are obtained by measuring changes in the vibration frequency of each of the wires supporting the bucket. Each of the three wires has a resonance frequency (f) as a fundamental measurement. Accumulated precipitation can therefore be expressed as a function the difference between the resonance frequency (f) and the "empty" bucket vibration frequency (f_0) based on equation 1:

$$Precipitation = A\ (f\text{-}f_0) + B(f\text{-}f_0)^2. \qquad (1)$$

Here, A and B are calibration constants, and the vibration frequency associated with the empty bucket (f_0) is determined each time the instrument is serviced. The coefficient A may also need to be adjusted after each servicing.

II. Possible problems affecting the measurements.

The mechanics of the instrument suggest six possible problems that could affect the record of precipitation measurements. These problems would be able to be detected based on different sets of signals and are likely to require various diagnostic and repair times. These six possible problems and their probable diagnostic and repair times are summarized below.

1. *A wire could break*. In a three-wire system, if a wire breaks, the other two wires give worthless information. Although wire breakage is extremely rare, it is three times more common in a three-wire system. The signal for a problem of this type should be easy to detect, and would indicate a problem that must be fixed immediately in order to collect worthwhile data.
   Lag time for diagnosis: one day.
   Lag time for repair: repair should be made as immediately as possible.

2. *The "plucking" / "hearing" system within a sensor could go bad*. This problem is likely to occur in varying levels of severity, and can be detected advantageously by the three-wire system. The redundancy provided by the three-wire combination will allow for continued data should this problem occur, and will also provide past information necessary for correcting suspicious values. Because of the small range of

variations in the vibration frequencies during non-precipitating time periods, these problems could be difficult to diagnose until data from a precipitation event are available.
Lag time for diagnosis: likely to require a precipitation event.
Lag time for repair: problem should be fixed at next site visit.

3. *The calibration of a wire could change*. In general, the wires show strong stability with little calibration drift. Should a change occur, this problem could be diagnosed from the data, although it may also mimic a problem with the overall instrument alignment.
   Lag time for diagnosis: days to months.
   Lag time for repair: wire system will need to be recalibrated or replaced during next site visit.

4. *The bucket could overfill, either with precipitation or debris*. Geonor recommends emptying the accumulation buckets every six months: this timeframe may or may not be appropriate for all sites. Examining the data can provide an indication of when a bucket is full because a full bucket will cause a continuous string of non-precipitating days to be reported. In most cases, this problem can likely be anticipated and remedied before it occurs. Debris in buckets is not able to be diagnosed from the data alone and can only be detected from a site visit.
   Lag time for diagnosis: days to weeks.
   Lag time for repair: next site visit.

5. *The bucket could shift out of alignment*. The three-wire system allows for small misalignments without detriment to the quality of the data. It is not presently known how large a misalignment is too large, but time and site experience will provide this information. Alignment can be easily monitored, and misalignments can occur gradually or suddenly. A large misalignment will indicate a problem requiring immediate attention.
   Lag time for diagnosis: one day.
   Lag time for repair: problem should be fixed as immediately as possible.

6. *The data acquisition system could fail*. Problems with the data acquisition system are likely to involve numerous signals, including missing or redundant data, strange data spikes, incorrect date/time stamps, or corrupted files. The problems should be able to be quickly diagnosed.
   Lag for diagnosis: one day (?).
   Lag time for repair: problem should be fixed as immediately as possible.

III. Evaluation of the NCAR Marshall field site data.

From fall 2000 through summer 2002 six Geonor precipitation gauges were operated at the NCAR Marshall field site near Boulder, Colorado (Duchon, 2002; Duchon et al., 2003). Chuck Wade in NCAR's Research Applications Program provided the archived data files as well as much useful discussion for the analysis. The archived measurements from the six Geonor gauges were evaluated for qualifiers to suggest guidelines for assuring the quality of the data. The NCAR data were reported as one-minute values, rather than the 15-minute averages to be archived by CRN. We worked with the one-minute values of both the raw frequencies and the accumulated precipitation values to determine expected ranges for the variability as well as the wire-to-wire differences. These ranges are outlined in Appendix 2.

Each data file contains one day of 1-minute values corresponding to:

- gauge readings for each of three wires for each of the six gauges;
- the three-wire average for each minute;
- frequencies for each of the three wires in each of the six gauges;
- the three-wire average frequency;
- temperature, wind speed, and wind direction.

The data record began December 8, 2000, but the files through December 20, 2000 were found to be incomplete. Changes in the way the data were reported occurred on October 18, 2001 and November 01, 2001. On November 20, 2001, the gauge in the Wyoming wind shield was dropped from the record, and apparently replaced with values for a gauge in an NCAR Double Alter wind shield. It is not clear whether only the wind shield was changed or whether a different gauge was introduced.

One focus of the NCAR study was to determine which wind shield would contribute to a more accurate measurement of the precipitation, especially during periods of snow (Wade and Cole, 2001). Ultimately, the small double fence intercomparison reference (SDFIR) was selected for use in CRN. Examples of the three-wire analyses for the gauge in the SDFIR wind shield are presented in a supplementary appendix to this report.

The gauge values for the six instruments typically fell within a range from 8 to 12 mm over the entire period of record. The corresponding frequency values ranged from around 1000 to 3000 Hz. Figure 3 shows the vibration frequencies for each of the three wires on one of the instruments. Each increase in the vibration frequency corresponds to a precipitation event. The frequency responses during time periods of non-precipitation and precipitation are shown in Figure 4. Any changes in frequency during a non-precipitation period are very small. During a precipitation period, however, each of the wires should show a similar increase in vibration frequency, corresponding to increases in the weight of the bucket as precipitation accumulates.

The one-minute values were examined for each day. For each value, the wire-to-wire variations were assessed. The variations among the three-wire frequencies were generally found to be less than one percent. Plots of wire-to-wire differences in frequency (Figure 5) and precipitation (Figure 6) show that epochs can occur in terms of how the wires behave, but the differences are not large, and the reasons for these changes are unknown. Examining these wire-to-wire differences can help us understand the overall behavior of the instrument and allow us to determine when certain wires showed measurements that deviated from the normal range.

Daily standard deviations of the three-wire frequencies also tended to be small, but are non-zero. During days experiencing precipitation events, the standard deviation is observed to increase. The overall behavior of the wires is observed to track well during precipitation events. Differences in wire behavior during a precipitation event would indicate a problem needing to be investigated.

IV. Recommendations for automating the data quality assurance.

Quality assuring the three-wire Geonor data will require examining and considering site visit reports as well as the recorded data. The data should be evaluated on minute (or 15-minute), daily, and annual timeframes. Agreement among the three wires is likely to be determined based on appropriate statistical techniques. These techniques and the threshold levels may differ with site, as some sites may be more affected than others by external influences or large natural variability. An automated function oddball, comparing levels of disagreement based on the two variables in highest agreement, may be appropriate at many of the locations.

A multi-pass approach is recommended for assuring the quality of the precipitation measurements. In each series of tests, the measured values will be evaluated at four levels, with thresholds indicating both suspicious and alarm data for the network and at the individual site. The thresholds can be derived from the known operating procedures of the instrument and from known, expected climatology at each of the sites. Preliminary data collected at each location will also help in developing specific thresholds for that site. The data will be tested against four levels of thresholds: a suspicious value for the site, an alarm value for the site, a suspicious value for the network as a whole, and an alarm value for the network as a whole. The suspicious values may be able to be verified or corrected for eventual use in analysis. Alarm values would be considered bad data and eliminated from any long-term climate analysis.

Figures 7 and 8 provide an example of how these thresholds can be derived. Figure 7 shows measurements recorded by one of the NCAR Geonor gauges over the course of one day. On this particular day, we see two large, upward jumps in data. For each day in the analysis period, we recorded the maximum spike (upward or downward jump) in the data. Out of 1,440 one-minutes values for each wire for each day, we retained only three values, corresponding to the highest spike for each wire. The results for ~200 days of instrument operation are shown in Figure 8 and indicate that only six of the 600 values were over 10.0 Hz. Analyses of this type can help determine thresholds for what is reasonable and what is an alarm in terms of what we expect from the data. In general, spikes occurring in the data are not problem, but too many over a given time period will require that the values be investigated.

The multi-pass testing is likely to progress through four tiers. The first two tiers should be completed daily following the automatic download of the data file. The second two will likely be completed at less frequent, perhaps weekly or monthly, intervals. Each tier or pass of testing is described below.

Pass 1. The first pass processing should be completed daily following each file download and should address the following requirements:

- A daily download file should exist at each site, and the file should be of appropriate size.
- The daily file should contain only readable, numeric ascii characters.
- The header data (including site location, calibration numbers, and date) should be checked to insure they are appropriate.

Pass 2. The second pass processing will also be completed daily following the file download and will examine the one-minute or 15-minute values based on the following criteria:

- The magnitudes of frequencies should be between approximately 1000 and 3000 Hz.
- The wire-to-wire variations during non-precipitating time periods should be small, but should not be zero.
- Upward jumps (one minute to the next) should be within a prescribed range for a particular site.
- Downward jumps should always be small.
- Any outliers should be flagged.
- The overall range (difference between max and min) of the data should fall within a predetermined range for a given site.
- On days with no precipitation, there is likely to be little correlation among the three sensors.

- On days with precipitation, there should be strong correlation among the three sensors.

- Each day, whether with precipitation or not, should indicate general agreement between the derived precipitation of the three sensors.

Pass 3. The third pass processing will be completed weekly or monthly and involve examining running averages of the daily precipitation values. Running averages should be evaluated for each week, for each three-month period, and over the course of a year and evaluated in terms of the following criteria:

- Over the course of a week, the daily averages should not decrease or differ more than a prescribed range for each site.

- Over the course of the three-month period, the daily averages should not decrease or differ more than a prescribed range.

- Over the course of a year, the daily averages should not decrease or differ more than a prescribed range.

Pass 4. The fourth and last pass of processing should be completed monthly or quarterly and involves verifying the preliminary QA values and flags with information from site visit reports. Site visits will be required for the data to receive full quality assurance and should provide information on several factors:

- The contents of the bucket and alignment must be noted and considered.

- Records of the times the bucket was emptied and restocked are necessary for resetting data management files.

V. Quality assurance flags.

Two types of quality assurance flags will be used. The first is a flag for data release and archival. These flags will be coordinated by CRN, and have not yet been determined. The other type of quality assurance flag will be used by CRN personnel and provide information on which test failed, at which site, when, and in which line of data. The flag will indicate whether the test failed because the value was deemed to be suspicious (exceeding the generally acceptable range), or because it was determined to be an alarm. The flag will also specify whether the suspicious or alarm levels were exceeded based on the quality assurance parameters for the site or for the network as a whole. The flags can ultimately be cross-linked with possible physical explanations.

VI. Conclusions.

The CRN is the largest network of Geonor precipitation gauge instruments and the only to use the three-wire variation. This three-wire variation minimizes the effect of small leveling problems on the data, but cannot provide a foolproof method of obtaining measurements if one of the three wires should break. Fortunately, the wires used in the Geonor gauge have very long-term success records, and wire failures occur only rarely. Other problems, such as a lost or spurious signal from one of the sensors, should not affect the quality of the data obtained from the other two wires. This redundancy will make these types of problems easier to detect and will also assist in determining if data need to be corrected.

The quality assurance of the Geonor data is likely to require a multi-pass process. The first pass processing will verify the existence and formatting of the daily download files at each site. The second pass processing will examine the one-minute values using seven different tests, each with four possible outcomes corresponding to suspicious values and alarm values for both the site and the network as a whole. The third pass processing will evaluate running averages of the daily values for one-week, three-month, and one-year time periods. As with the second pass processing, the values will be checked against four different criteria, corresponding to suspicious values and alarm values for both the network and the site. The last tier of the QA process, the fourth pass processing, involves verifying the data against site visit reports and making any necessary adjustments before a final approval of the quality of the data.

Developing this multi-pass quality assurance algorithm for the Geonor precipitation data will be an iterative process. Flowcharts outlining the procedures for assuring data quality are included in Appendix 1 and are based on our best understanding of the data and instrument behavior at this time. The problems most likely to be encountered have been identified and estimates have been made concerning their diagnostic lag times. Many problems are likely to be diagnosed with a lag time of only one day.

Because precipitation amounts can vary greatly with location, quality assurance of the Geonor data will require an iterative development process as normal and anomalous behavior is identified. Much of this iterative process is likely to occur during the first year as site-dependent qualifiers are developed.

References:

Baker, B. Science Plan for the Analysis of NCAR Raingauge Data, National Climatic Data Center, Asheville, NC.

Duchon, C.E., Results of laboratory and field calibration-verification tests of Geonor vibrating wire transducers from March 2000 to July 2002. Report to the U.S. Climate Reference Network Management Office, July 2002.

Duchon, C.E., C.G. Wade, and J.A. Cole, Field studies of a vibrating wire precipitation gauge, AMS 83rd Annual Meeting, 2003.

Geonor T-200B Precipitation Gauge Users Manual, Geonor Inc., Milford, PA.

Wade, C. and J. Cole, Final report to the CRN Management on the Snow Gauge and Wind Shield Evaluation Studies Conducted at NCAR from January-April 2001, National Center for Atmospheric Research (NCAR), NCAR Research Applications Program (RAP), October 15, 2001.

GEONOR T-200B PRECIPITATION GAUGE

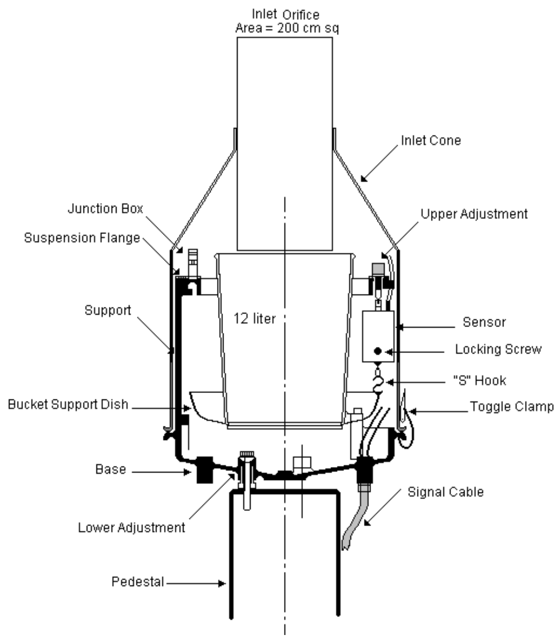

Figure 1. Schematic of the Geonor instrument. The instruments used by the CRN replace two supporting struts (shown on the left side of the diagram) with additional wire/sensor units to create a three-wire system less sensitive to leveling.

Figure 2. Looking downward at the Geonor T-200. The bucket is suspended by three cylinders, each housing a vibrating wire. The vibrating wires are driven by a spectrum of frequencies and vibrate at their resonance frequencies. The resonance frequency of each wire depends upon the tension in the wire, which is directly related to the amount of weight in the bucket.

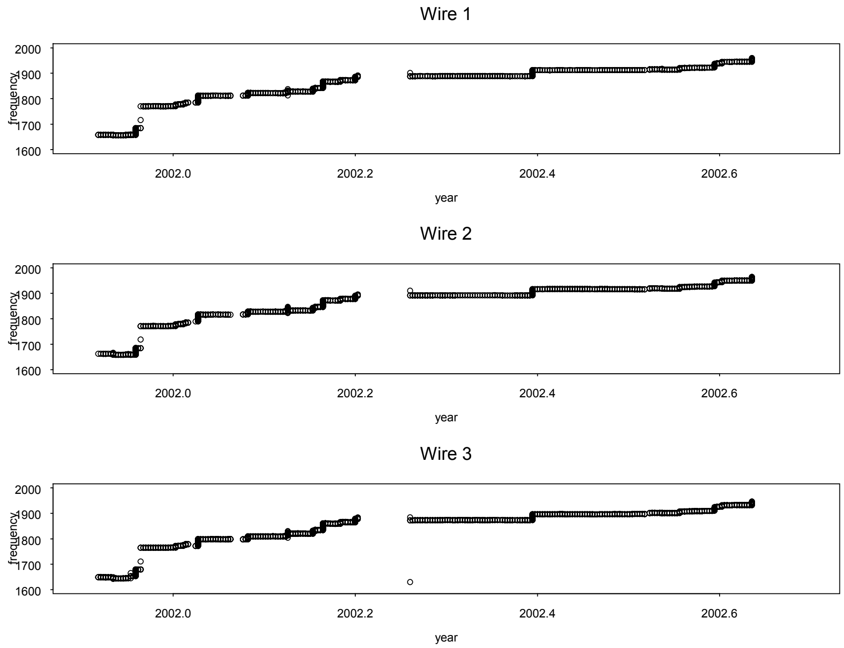

Figure 3. Three-wire results showing the change in vibration frequency over the operating period of the instrument. These increases in frequency translate to increases in the accumulated precipitation collected by the Geonor precipitation gauge.

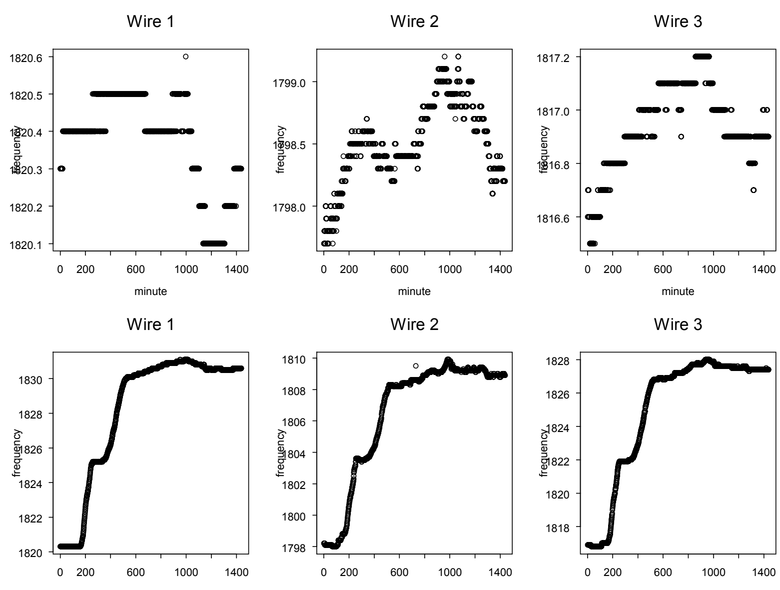

Figure 4. Three-wire values recorded during periods without precipitation (top row) and with precipitation (bottom row). During non-precipitating periods, the three wires show variations from one another, but the magnitude of any deviations is very small. During precipitating periods, the three wire readings show good agreement, and changes in the vibration frequencies are much more pronounced.

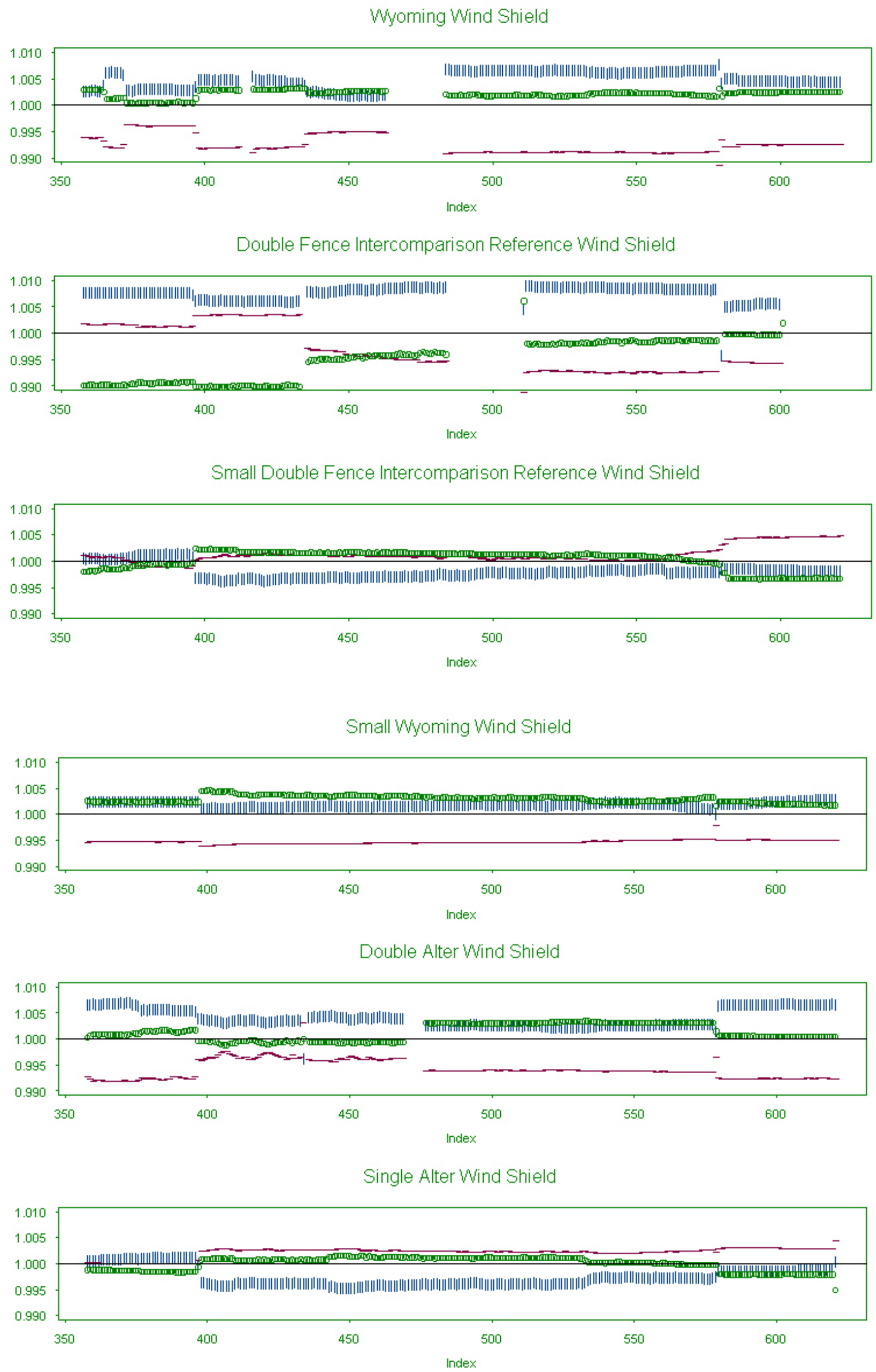

Figure 5. Percent deviations of each wire frequency from the three-wire average, shown for each of the six gauges.

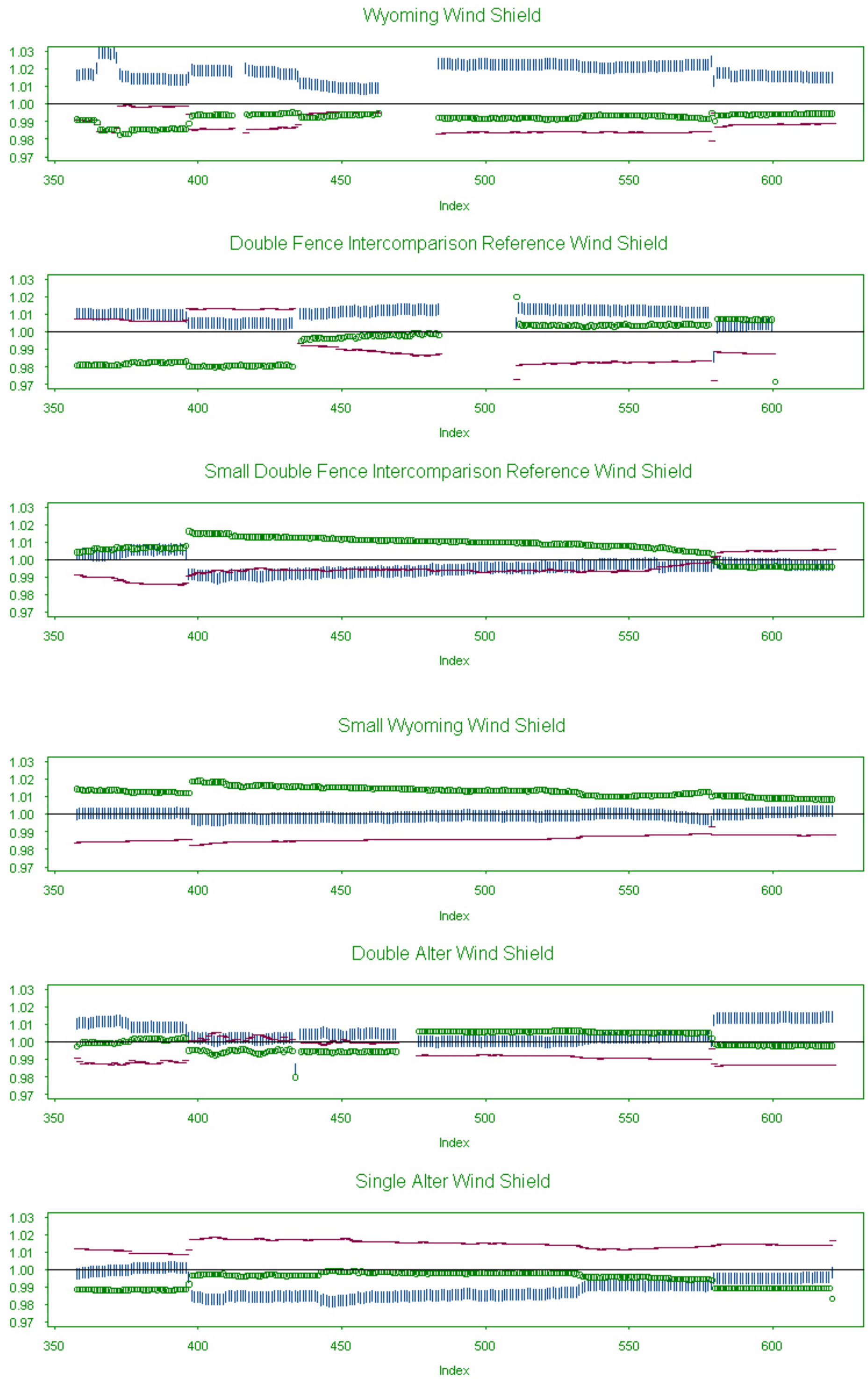

Figure 6. Percent deviations of each wire gauge reading from the three-wire average, shown for each of the six gauges.

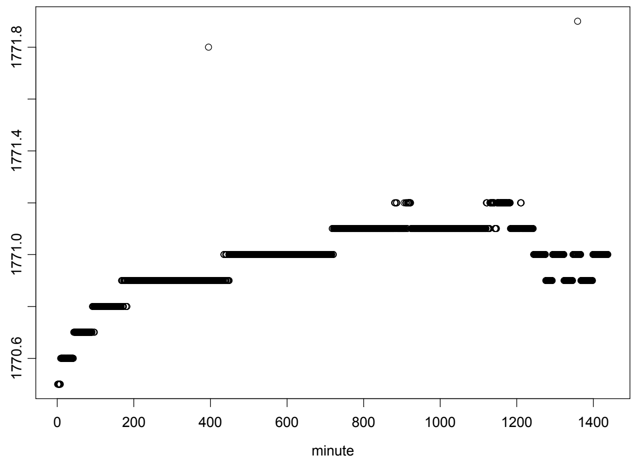

Figure 7. Recorded frequencies for a three-wire Geonor instrument over the course of one day. On this day, two large, upward spikes in the data are observable.

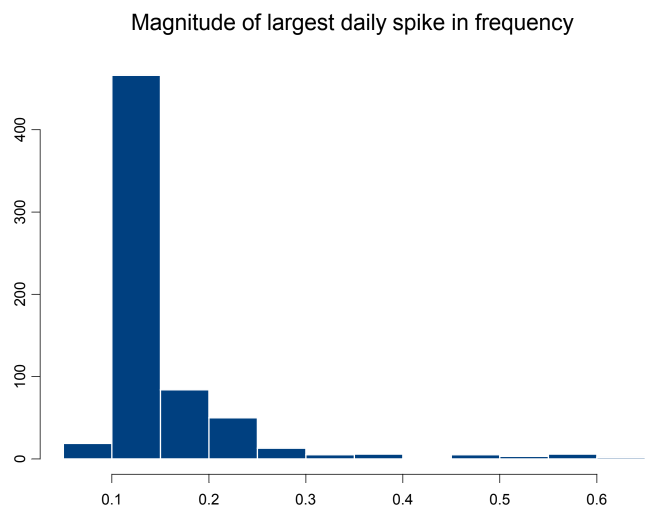

Figure 8. Magnitudes of the largest daily spikes for each of the three wires recorded over ~200 days. The values used to generate this histogram represent the largest spike for each wire for each of the 1,440 minutes in a day. The process was repeated for ~200 days so that ~600 values are shown here. Of these values, only six indicated a jump greater than 10 Hz.

Appendix 1

Flowcharts documenting the recommended Geonor QA scheme. The first flowchart provides an overview of the multi-pass processing required to assure the quality of the Geonor data. Four additional flowcharts show the steps specific to each processing pass.

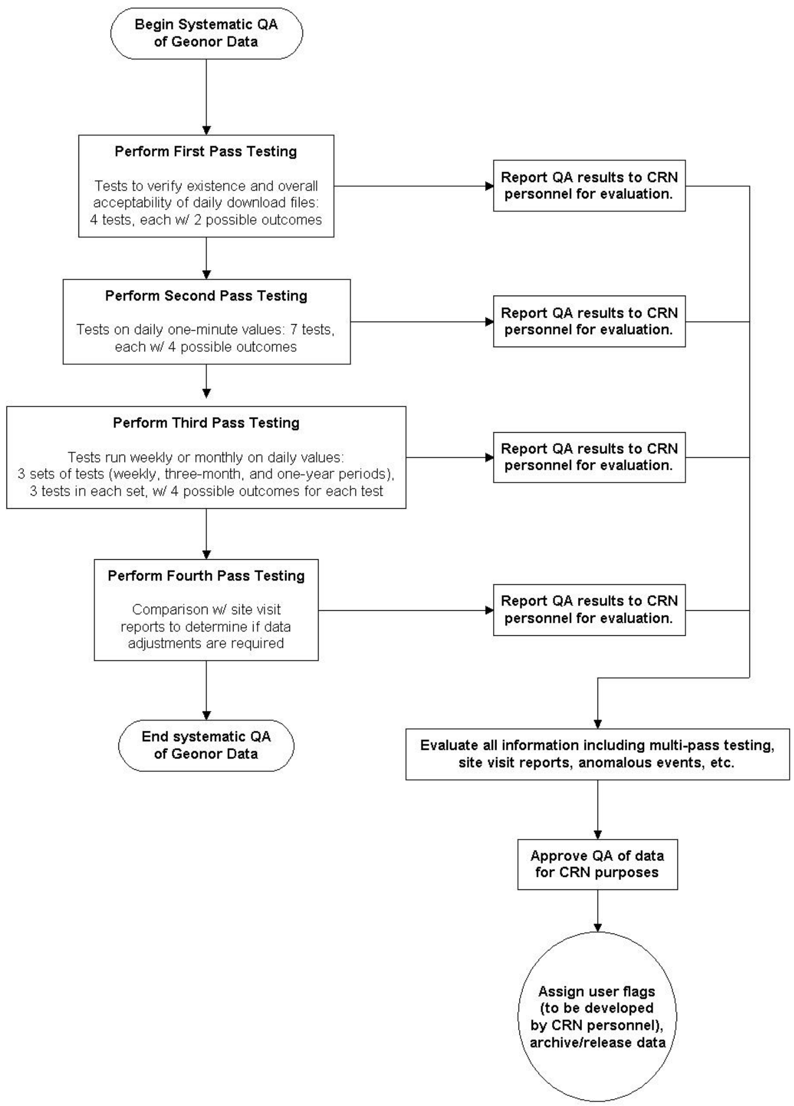

Figure A1.1. Overview of the multi-pass algorithm for quality assuring the Geonor data. Each series of tests will generate a report to be evaluated by CRN personnel to determine if actions need to be taken to control or assure the quality of the data. Once the multiple passes are completed, the data can be quality assured for CRN purposes. User flags will be assigned by CRN in a later process.

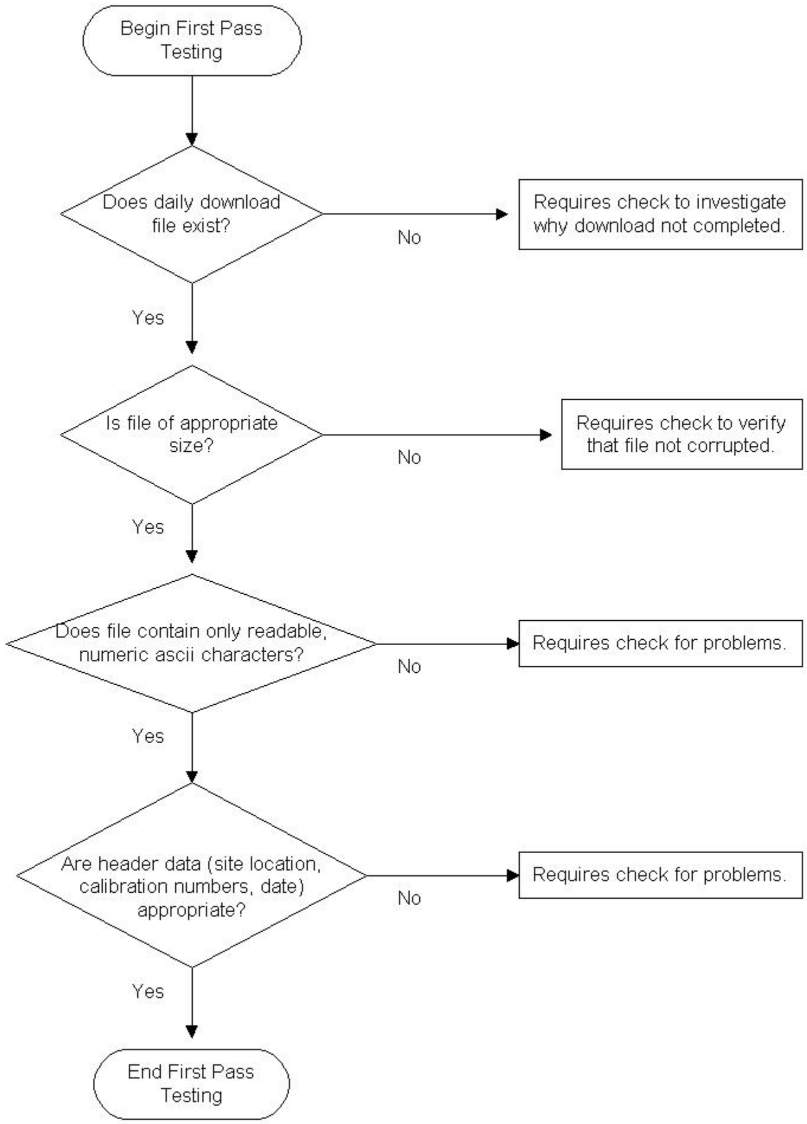

Figure A1.2. Outline of the first series of tests to assure the quality of the Geonor data. These tests should be completed daily to verify that downloads are proceeding without difficulty and that there are no corruptions within the files.

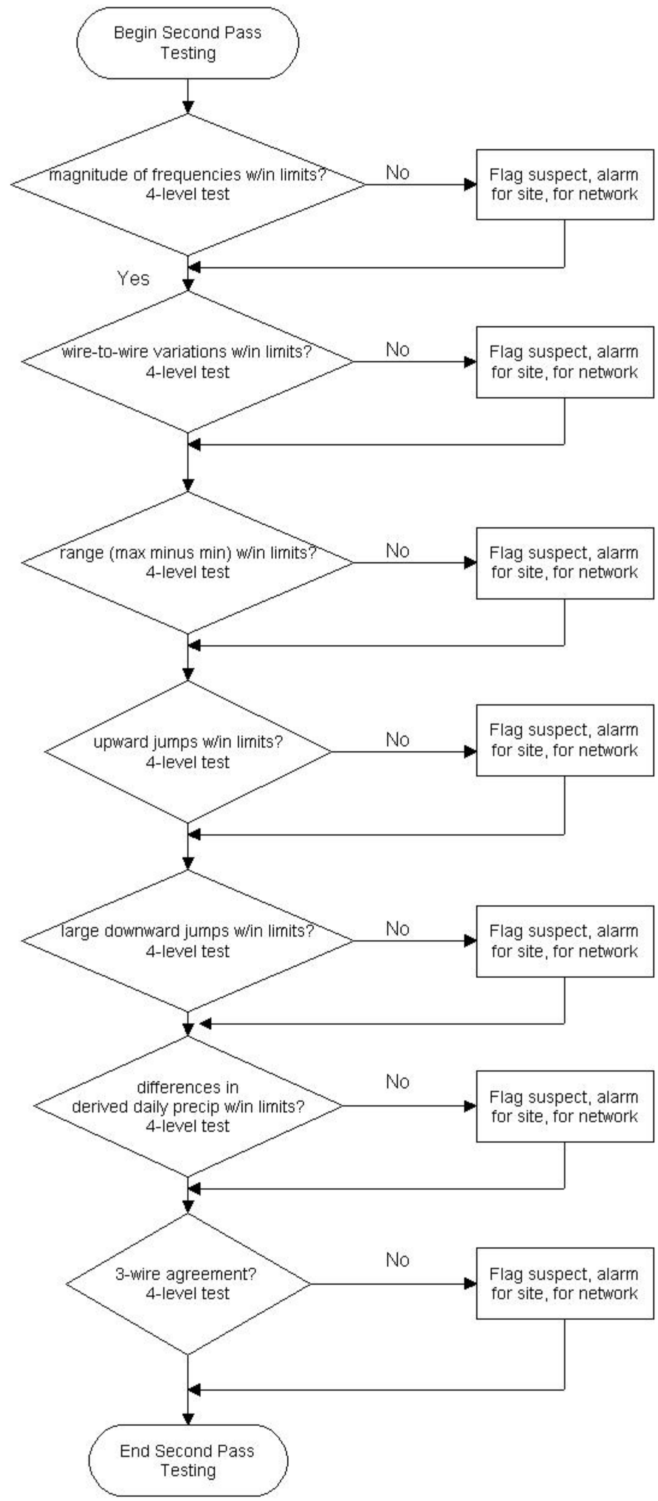

Figure A1.3. Outline of the second series of tests to assure the quality of the Geonor data. These tests will examine the one-minute (or 15-minute) frequency and precipitation values to assure that there are no sudden changes or shifts in the data. These tests should be run daily on the download files so that any problems can receive immediate attention.

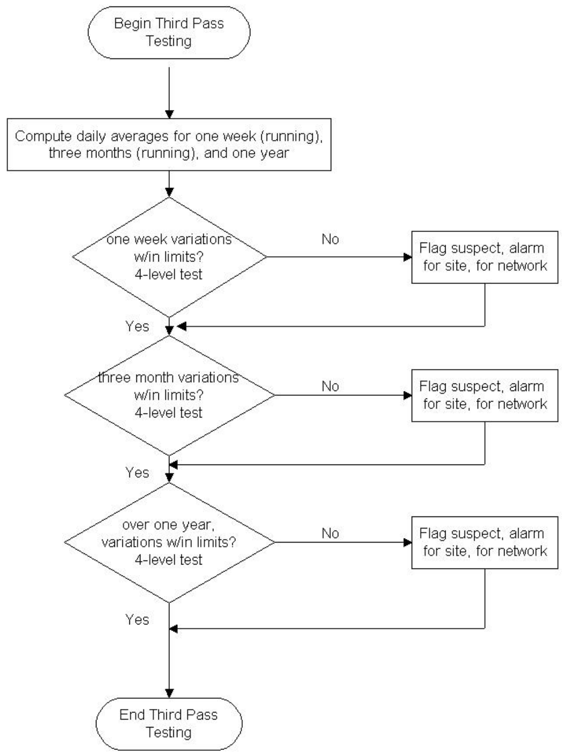

Figure A1.4. Outline of the third series of tests to assure the quality of the Geonor data. These tests should be completed weekly or monthly to evaluate the daily averages over one week, three months, and one year. The results will indicate whether changes or shifts are occurring in the data over greater-than-daily timeframes.

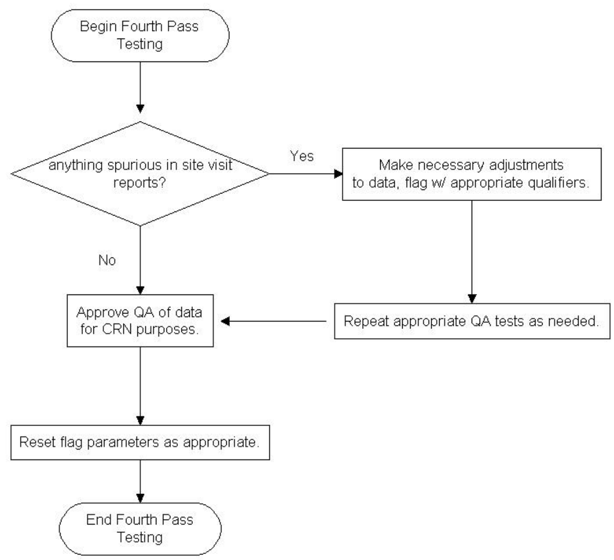

Figure A1.5. Outline of the fourth set of tests to assure the quality of the Geonor data. The fourth pass processing involves verifying the data against information provided in site visit reports and making any appropriate adjustments. This step is required before the data can ultimately be quality assured for CRN purposes.

Appendix 2

Suggested acceptable and unacceptable ranges for 4-level test parameters for Geonor gauges in Boulder, Colorado.

One-minute values, tested daily		
	Acceptable range	Unacceptable/Alarm
Frequency magnitudes	1000 < freq < 3000 Hz	
Precipitation magnitudes	0 < precip < 400 mm	600 mm (this is the bucket capacity)
Variance (non-precip days)	small	zero
Frequency variance (precip days)	variance < 300	> 1000
Precip variance	variance < 0.05	> 0.1
Freq max minus min	diff < 50	> 100
Precip max minus min	diff < 0.2	> 0.5
agreement among 3-wire freqs	should be good for all days	
agreement among 3-wire precip	should be good for all days	
Upward jumps in freq (by minute)	jump < 25 Hz	> 100 Hz
Downward jumps in freq (by minute)	jump < 2 Hz	> 10 Hz
Upward jumps in precip (by minute)	jump < 0.3 cm	> 1 cm
Downward jumps in precip (by minute)	jump < 0.2 cm	> 1 cm
Frequency outliers	Outlier diff < 0.5	> 1 Hz
Precipitation outliers	Outlier diff < 0.2	> 0.5 cm

Appendix 3

Figure A3.1 shows NWS-measured precipitation and snow for the December 2000-August 2002 time period. Figure A3.2 shows the daily high and low temperatures for the same time period. An understanding of the climatology for an area can help develop criteria for quality assuring the site's data. Analyzing wire-to-wire differences and overall stability requires evaluating frequency and gauge reading ranges for both wet and dry periods.

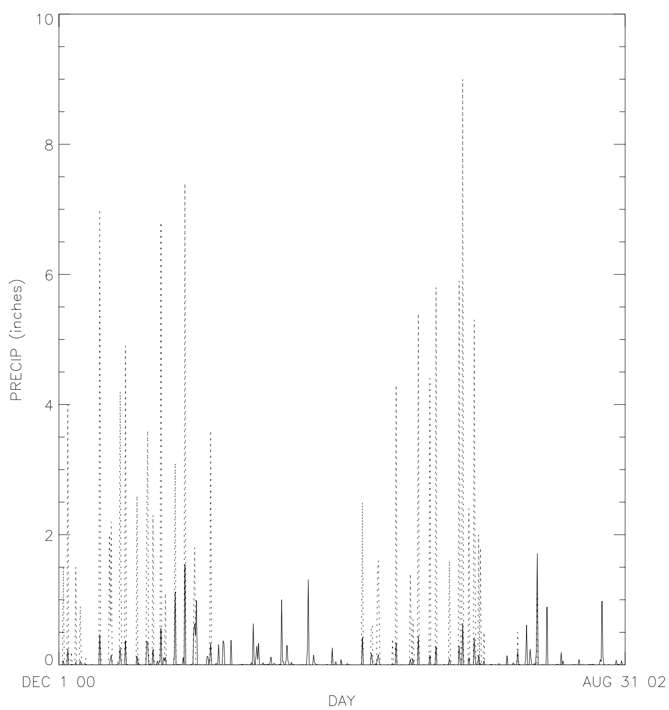

Figure A3.1. NWS-measured precipitation (solid line) and snowfall (dotted line) for December 1, 2000 through August 31, 2002 for Boulder, Colorado. Obtained from the NOAA Climate Diagnostics Center.

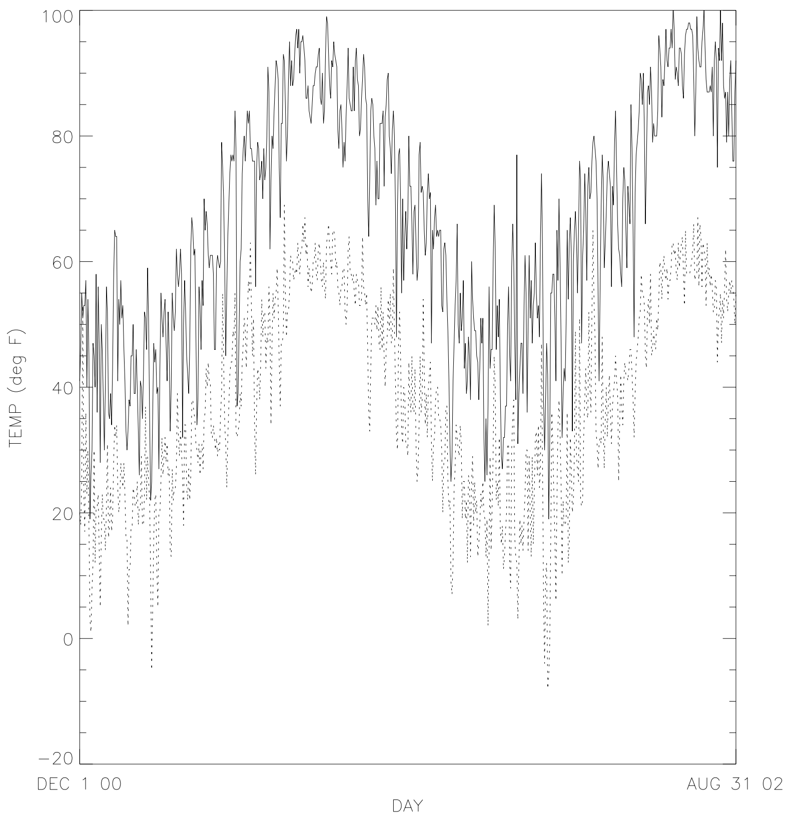

Figure A3.2. Daily high (solid line) and low (dotted line) temperatures for Boulder, Colorado. NWS-measured observations obtained from the NOAA Climate Diagnostics Center.